METHOD FOR ADJUSTING THE PITCH AND ROLL STATIC TORQUES IN A DISK DRIVE HEAD-SUSPENSION ASSEMBLY

Technical Field

5   This invention relates generally to magnetic recording disk drives and more particularly to a method for adjusting the static torque applied to an air-bearing slider in a disk drive head-suspension assembly.

Background of the Invention

10   Magnetic recording hard disk drives use a read/write transducer or head mounted on an air-bearing slider for reading and/or writing data to the disk. The slider is attached to an actuator arm by a suspension and positioned very close to the disk surface by the suspension. The combination of the slider and suspension is called the head-suspension assembly (HSA). There are typically a stack of disks in the disk drive with a HSA associated with each disk

15   surface in the stack.

The separation between the slider and the disk surface is called the flying height. The slider rides on a cushion or bearing of air generated by the rotation of the disk. The slider is attached to a flexure on the suspension and the suspension includes a load beam that applies a load force to the slider to counteract the air-bearing force while permitting the slider to "pitch"

20   and "roll". The flying height and flying dynamics of the slider are influenced by factors such as the rotation speed of the disk, the aerodynamic shape of the air-bearing surface (ABS) of the slider, the load force applied to the slider by the suspension, and the pitch and roll torques applied to the slider by the suspension.

The desired pitch and roll torques are determined from the pitch static attitude (PSA)

25   and roll static attitude (RSA) and the pitch and roll stiffnesses (K_p, K_r) of the suspension. These torques are called the pitch static torque (PST) and roll static torque (RST). Thus,

$PST = K_p PSA$; and

$RST = K_r RSA$.

The slider pitch and roll dynamic or flying attitudes are determined by a force balance between the air-bearing force and the suspension load force and static torques (PST and RST). The deviations of the dynamic attitudes should be very small to achieve good performance and high reliability. The slider dynamic attitudes are very sensitive to PST and RST, especially in disk drives that use very small sliders or very-low-flying sliders, or disk drives with a relatively low rotational speed, such as the commercially available 1-inch disk drives. Therefore, it is important to reduce deviations in PST and RST and assure that all HSAs are manufactured with essentially the same PST and RST values.

In conventional HSA manufacturing, K_p and K_r are assumed to be constants that do not vary from one HSA to the next. Then, the deviations of PST and RST (dPST and dRST) can be expressed as:

$$dPST=K_p dPSA; \text{ and}$$

$$dRST=K_r dRSA, \text{ where dPSA and dRSA are the deviations in PSA and RSA,}$$
respectively.

Therefore, to reduce dPST and dRST, dPSA and dRSA are reduced by adjusting PSA and RSA. For example, some disk drive manufacturers mechanically adjust the PSA and RSA ~~after assembly of the HSA~~ by bending a suspension component, such as the flexure. U.S. Patent 6,011,239 describes a method for adjusting the PSA and RSA to the desired values by first measuring the PSA and RSA and then laser heating the flexure.

Typically, the standard deviation of K_p and K_r is in the range of about 5% to 10%. However, it has recently been determined that the standard deviation of K_p and K_r can be as large as 23%. When there are relatively large non-zero PSA and RSA values (such as a PSA of 2.0 degrees), K_p and K_r deviations can also result in large dPST and dRST deviations even though dPSA and dRSA are zero. In reality the effect can be worse because adjustment of PSA and RSA can also change K_p and K_r.

Thus, what is needed is an HSA manufacturing process that adjusts PST and RST and assures that all HSAs have substantially the same values of PST and RST, regardless of deviations in K_p and K_r and PSA and RSA.

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Summary of the Invention

The invention is method for adjusting the pitch and roll static torques (PST and RST) on a slider in a disk drive head-suspension assembly (HSA) during manufacturing to assure that each HSA is manufactured with acceptable PST and RST values. The method includes measuring each slider's pitch and roll static attitudes (PSA and RSA) and determining the pitch and roll torsional stiffnesses for each HSA. These values are then used to calculate the required amount of adjustment to PSA and RSA to achieve the desired values of PST and RST for each slider. The suspension is then adjusted, such as by heating the flexure with a laser.

The pitch and roll torsional stiffnesses of each HSA are determined from the slider's pitch and roll natural frequencies and effective moments-of-inertia. The moments-of-inertia are substantially the same for each slider and may be calculated or measured from a sample of HSAs. In the measurement method, each of a sample of HSAs is vibrated and the response is measured with a laser Doppler vibrometer to arrive at pitch and roll natural frequencies. Each of the samples is then subjected to known torques and the angular deflections measured to arrive at measured torsional stiffnesses. The resulting measured frequencies and torsional stiffnesses are used to calculate the moments-of-inertia for each sample, and an averaging or other statistical technique is used to arrive at fixed values for slider pitch and roll moments-of-inertia that are used in the method to adjust PST and RST for each HSA during manufacturing.

During manufacturing each slider's pitch and roll natural frequencies are measured using a laser Doppler vibrometer. These measured values are then used with the fixed values of slider pitch and roll moments-of-inertia determined from the prior HSA samples to determine the pitch and roll torsional stiffnesses for each slider.

Thus each slider's pitch and roll torsional stiffnesses are measured during manufacturing. This avoids the problem of relying only on a measurement of PSA and RSA to assume that the PST and RST values are acceptable. Each slider is now manufactured to the desired values of PST and RST. This method thus assures that all sliders will have

5   substantially the same values of PST and RST.

For a fuller understanding of the nature and advantages of the present invention, reference should be made to the following detailed description taken together with the accompanying figures.

10   **Brief Description of the Drawing**

FIG. 1 is a side view of a head-suspension assembly in the unloaded state.

FIG. 2 is a side view of a head-suspension assembly with the slider in the loaded state on the disk.

FIG. 3 is a side view of a head-suspension assembly according.

15   FIG. 4 is an end view of the head-suspension assembly shown in FIG. 3 showing the roll static attitude of the slider.

FIG. 5 is a side view of a head-suspension assembly illustrating the flying height of the slider.

FIG. 6 is a schematic diagram of an apparatus for performing the static torque

20   adjustment method according to the present invention.

FIG. 7 is a flow chart for the static torque adjustment method according to the present invention.

FIG. 8 is a view of the air-bearing surface (ABS) of a slider showing locations where the laser spot of the laser Doppler vibrometer (LDV) is aimed for the measurement of the

25   slider pitch and roll natural frequencies.

FIG. 9 is a view of a slider from the ABS showing a portion of the flexures where laser pulses are directed for adjusting the pitch and roll static attitudes.

Detailed Description of the Invention

FIG. 1 illustrates a head-suspension assembly (HSA) 10 comprised of a load beam 14 an air-bearing slider 18, and a gimbal or flexure 36 connecting the slider 18 to the load beam 14. The slider 18 includes a trailing surface 19, where the read/write head is located,

5   and an air bearing surface (ABS) 20. The load beam 14 includes a hinge region 22 which is connected by a connector 23 to an actuator arm 26. The load beam 14 is bent at an angle Θ relative to the hinge region 22. The load beam 14 has a top side 28 and a bottom side 29. The top side 28 is the side of the load beam 14 on which the slider 18 is mounted, and the bottom side 29 is the side of the load beam 14 opposite to the top side 28.

10   The actuator arm 26 is connected to an actuator 30 which functions to move the slider 18 relative to the surface of a rigid magnetic recording disk 34 (shown in FIG. 2). The actuator arm 26 has a top surface 31 that faces in the same direction as the top side 28, and a bottom surface 32 that faces in the same direction as the bottom side 29. The load beam 14 is attached to the actuator arm 26 along the surface 31 by the connector (base plate) 23. The

15   slider 18 is attached to the load beam 14 by a flexure 36 and a dimple 38. The flexure 36 is a flexible member that allows the slider 18 to pivot on the dimple about the pitch axis (the transverse or Y axis) and the roll axis (the longitudinal or X axis). The load beam 14 imposes a counteracting load force to the slider 18 at the dimple 38 to balance the air bearing force from the rotating disk 34. As is well known in the art, a second HSA is typically attached to

20   the bottom surface 32 of the actuator arm 26. The second HSA is identical to HSA 10 but faces in the opposite direction so that its slider can engage with a second disk in the disk stack.

FIG. 2 illustrates the relationship of the HSA 10 to the disk 34 when the disk 34 is not rotating. In the configuration shown in FIG. 2, the HSA 10 is said to be in the "loaded" state.

25   In the loaded state, the load beam 14 and the flexure 36 are bent down by the disk 34 so that the angle Θ between the load beam 14 and the hinge region 22 is close to zero. Because the hinge region 22 resists this deformation, a load force (also called the gram load) is transmitted through the load beam 14 and dimple 38 to the slider 18. The distance between the ABS 20 of the slider 18 and the top surface 31 of the arm 26 is called the "z" height. In cases where the

slider 18 is not present, the distance between the surface 31 and the top of the flexure 36 is called the z height.

FIG. 3 illustrates the load beam 14 held in the loaded state by an external means such as a pin 39. In this configuration, an angle α is defined by the ABS 20 and the top surface 31.

5 The angle α is referred to as the pitch static attitude (PSA) of the slider 18. Also in this configuration, an angle β is defined by the horizontal tilt of the ABS 20 relative to the top surface 31, as illustrated in FIG. 4. FIG. 4 is an end view of the HSA 10 with the load beam 14 held in the loaded state as was described in FIG. 3. The angle β is referred to as the roll static attitude (RSA) of the slider 18. The term "static attitude" is used to describe both

10 PSA and RSA together, with the PSA and RSA being separate components of the static attitude.

FIG. 5 illustrates the relationship of the HSA 10 to the disk 34 when the disk 34 is rotating. The rotation of the disk 34 causes the slider 18 to be positioned a distance "h" from the surface of the disk 34. The distance "h" between the ABS 20 and the disk 34 is referred to

15 as the slider "flying height" and represents the position of the slider 18 when the disk 34 is rotating during normal operation of the disk drive. If the flying height is not maintained within a certain range, the quality of the data read from or written to the disk 34 degrades.

Several factors contribute to the flying height. When the disk 34 is rotating, the rotation of the disk 34 creates a force (called an air bearing) that pushes the slider 18 away

20 from the disk 34. The load transmitted to the slider 18 by the load beam 14 and the pitch and roll torques exerted by the flexure 36 on the slider 18 oppose the air-bearing force. Therefore, adjustments to the angles Θ, α (PSA), and β (RSA) contribute to the final value of the flying height "h." Typically, the angle Θ is set at some predetermined value during the manufacturing process and provides the coarse positioning of the slider 18 which allows the

25 flying height to be maintained when the disk 34 is rotating. The PSA and RSA are also set at some predetermined values during manufacturing. However, as described previously merely adjusting PSA and RSA does not assure that dPST and dRST are small.

FIG. 6 illustrates the HSA adjustment apparatus 40 for adjusting the PST or RST in the HSA 10 to predetermined values in accordance with the present invention. The

apparatus 40 includes a pulsed laser 44, a detector 56, a slider excitation or vibration source 90, a laser Doppler vibrometer (LDV) 92, a signal processor 94, and a controller 60. The pulsed laser 44 delivers high energy radiation in short pulses to heat the flexure 38 at appropriate locations to change the PSA and RSA. The pulsed laser 44, detector 56 and

5   controller 60 together function as described in more detail in the previously cited '239 patent.

The detector 56 measures the PSA and RSA. As is well known in the art, detectors of this type comprise a single wavelength laser (e.g., a helium-neon laser) which is positioned to illuminate the slider 18 or the flexure 36, and project a pattern of reflected light onto a detector, such as a chart, a diode array or a charge-coupled device. The pattern of reflected

10   light is then compared to a standard pattern to yield the RSA or PSA. Generally, whenever PSA or RSA are being measured the slider 18 is held in place at the flying height (z distance) by an external means, such as the pin 39 shown in FIG. 3.

The controller 60 processes information from the detector 56 and the LDV 92 and controls the laser 44. In the preferred embodiment the controller 60 comprises a desktop

15   computer having a keyboard 80 for entering commands, a monitor 84 for displaying system information, and a computer 88 which includes a microprocessor-controlled motherboard, a hard disk drive and a floppy disk drive. The controller 60 also includes software running on the computer 88 for performing the calculations described below, including processing the output data from the detector 56 and LDV 92 and calculating the quantity of radiation from

20   the laser 44 required to adjust the PSA or RSA by a desired amount.

The vibration source 90 can be a shaker, such as a PZT device, or an electromagnetic shaker, attached to the fixture supporting the HSA 10. Alternatively, the vibration source 90 can be a stream of air directed at the slider from a source of pressurized air (not shown in FIG. 6). The LDV 92 measures the vibration response of the slider 18 and provides a velocity

25   signal to a signal processor 94. The LDV 92 may be a commercially available device, such as a single-beam Polytec Model 501. The signal processor 94 can be a Hewlett-Packard Analyzer Model 3562A or similar device. The signal processor 94 decodes the velocity signal from the LDV 92 to a frequency response of the vibrating slider 18 and provides the measured natural frequency to the controller 60. While a LDV is depicted in FIG. 6, other noncontact

devices for measuring the vibration response and thus the natural frequencies may be used, such as a capacitance probe.

The process to adjust the PST and RST to predetermined desired values according to the present invention is shown in the flowchart of FIG. 7. The process is shown as steps, but it is understood that the steps do not need to be performed in the order shown.

Step 1: Obtain moments-of-inertia I_p and I_r.

I_p and I_r are the effective slider pitch and roll moments-of-inertia, respectively, about the pitch and roll axes, respectively. The moments-of-inertia can be determined by calculation, measurement or a combination of calculation and measurement.

A) Calculation method: A finite element model of the HSA is built using conventional software, and based on the known dimensions and materials used in the HSA components, the moments-of-inertia are calculated.

B) Measurement method: A sample of HSAs are used to determine the natural frequencies F_p and F_r and torsional stiffnesses K_p and K_r of each of the samples. The natural frequencies are determined by exciting the sliders and measuring the natural frequencies with a LDV and signal processor. The torsional stiffnesses are measured by a standard static method, i.e., applying a known torque and measuring the angular deflection of each of the samples. The moments-of-inertia are then as follows:

$$I_p = K_p/(4\pi^2 F_p^2); \text{ and}$$
$$I_r = K_r/(4\pi^2 F_r^2).$$

The results from the samples can be averaged or other statistical techniques used to arrive at values of I_p and I_r.

C) Combination of calculation and measurement: Instead of measuring both the torsional stiffnesses and the natural frequencies of the sample HSAs, one or the other can be calculated from a finite element model, using commercially available software that calculates the dynamics of structural systems.

The effective I_p and I_r are usually larger than the I_p and I_r that are directly calculated by using slider dimensions and density, especially for a small slider. Deviations of Ip and I_r are

typically small for same group of parts, so it is preferred to use the same values of I_p and I_r for the same group of HSAs. However, for a larger slider and/or for higher accuracy, it is preferred to measure the slider's X and Y alignment relative to the dimple and slider dimensions to make a correction to I_p and I_r for each HSA.

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Step 2: Measure PSA and RSA

The initial pitch and roll static attitudes (PSA_i and RSA_i, respectively) of the HSA being adjusted are measured using any known prior art technique, such as described in the previously cited '239 patent.

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Step 3: Measure pitch and roll frequencies, F_p and F_r

The HSA is held in a fixture at its end that attaches to the actuator, with the slider in its free state. An excitation is applied to the slider to cause it to vibrate. The excitation can be applied to the fixture by a PZT or electromagnetic shaker. Alternatively, a continuous or pulse flow of air can be directed to the slider. In some disk drives that unload the slider off the disk and onto a ramp when the drive is not operating, the excitation can be applied at the drive level, such as by applying an excitation from the actuator, or by rotating the disk to generate an air flow to excite the slider.

The LDV 92 (FIG. 6) is used to measure the slider response and obtain values of F_p and F_r for the HSA being adjusted. FIG. 8 shows reference points 0 to 8 on the ABS of a slider where the LDV laser spot is to be directed. The following is one method to arrive at F_p and F_r.

a) Put the laser spot on the center (location 0) of the slider ABS, and measure a reference response $z0(t)$.

b) Put the laser spot on points 1 through 8, and measure the response $zi(t)$, $(i=1,...8)$.

c) Do a Fourier transform of $z0(t)$ and $zi(t)$ to obtain amplitudes of the Fourier transforms $Z0(f)$ and $Zi(f)$.

For only two responses:

$Zp(f)=Zi(f)-Z0(f)$, $(i=2 \text{ or } 7)$ for motion about the pitch or Y axis; and

Zr(f)=Zi(f)-Z0(f), (i=4 or 5) for motion about the roll or X axis.

Find the maximum peak in Zp(f) in a specified frequency range (typically the range is between 1500 and 3500 Hz) and its corresponding frequency is F_p.

Find the maximum peak in Zr(f) in the specified frequency range and its

5   corresponding frequency is F_r.

For more than two responses:

Measure more than two responses to obtain more reliable results by averaging. For example:

Zp(f)=(Z2(f)+Z7(f))/2-Z0(f) and its corresponding frequency is F_p.

10   Zr(f)=(Z4(f)+Z5(f))/2-Z0(f) and its corresponding frequency is F_r.

Step 4: Calculate required PSA and RSA shifts

The desired pitch and roll static torques are PST_z and RST_z, respectively. They are determined based on the disk drive design requirements to achieve the desired flying height

15   and flying dynamics for the particular slider design. The adjustments or shifts in PSA and RSA required to achieve PST_z and RST_z, respectively, are calculated from the measured pitch and roll static attitude components and the determined pitch and roll torsional stiffnesses. The shifts in PSA and RSA (dP, dR) to achieve the specified PST_z and RST_z are calculated from the following equations:

$$dP = \frac{PST_z}{4\pi^2 F_p^2 I_p} - PSA_i$$

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$$dR = \frac{RST_z}{4\pi^2 F_r^2 I_r} - RSA_i$$

Referring to step 5 of the flow chart of FIG. 7, if the dP and dR are smaller than a specified number (eP and eR, respectively), the process ends. If dP or dR is greater than eP or eR, respectively, then at step 6, the PSA and/or RSA are adjusted, after which steps 2

25   through 4 are repeated. After the process ends, if the measured PSA and RSA are also in the specified range, the HSA is acceptable. If either the PSA or RSA has been moved out of the

specified range in order to achieve PST_z or RST_z, respectively, the HSA is rejected.

The expression $4\pi^2 F_p^2 I_p$ is the pitch torsional stiffness K_p of the HSA being adjusted, so the above steps of determining I_p (step 1) and measuring F_p (step 3) can be considered together as determining the pitch torsional K_p stiffness of the HSA being adjusted. Similarly, the above steps of determining I_r (step 1) and measuring F_r (step 3) can be considered together as determining the roll torsional stiffness K_r of the HSA being adjusted.

Referring again to FIG. 6, the controller 60 uses the dP and dR values calculated in step 4 to determine the amount of laser energy to be applied to the flexure. As is known in the art and described in the previously cited '239 patent, this is accomplished by using a "look up" table derived from empirical calibration data, such as the number and intensity of laser pulses, or the power and duration of the pulses, required to bring about various PSA and RSA changes on similar suspensions.

FIG. 9 is a detailed view of slider 18 from the ABS side and shows portions of two legs 37, 39 of flexure 36. The load beam 14 is also shown in this view but the complete flexure 36 and the region where it attaches to the load beam 14 is not shown. The laser pulses are applied to the flexure legs 37, 39. Irradiation of just one leg will generally tend to change the RSA. Irradiation of both legs at single or multiple sites along the lengths of the legs bends the legs slightly in a manner that changes the PSA. Also, as is known in the art, the flexure can be bent mechanically to change the PSA and RSA.

While the present invention has been particularly shown and described with reference to the preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the spirit and scope of the invention. Accordingly, the disclosed invention is to be considered merely as illustrative and limited in scope only as specified in the appended claims.